



# Search for New Phenomena with Tau Pairs

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On behalf of the CDF Collaboration

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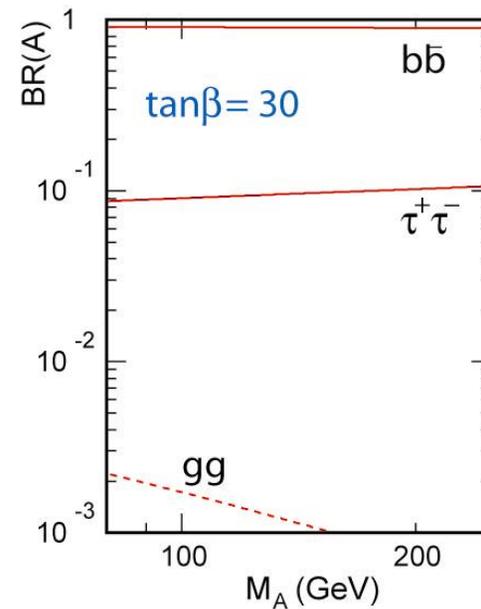
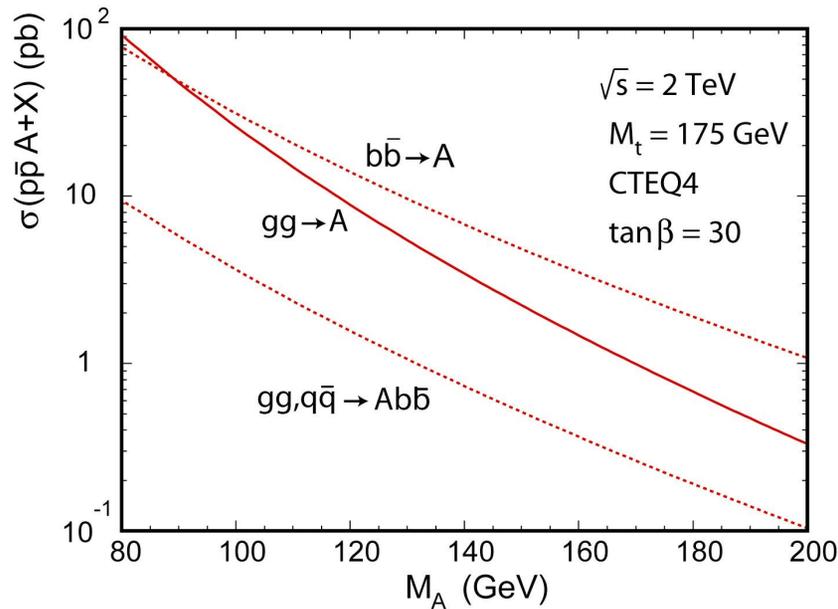
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## **Outline:**

- Motivation for the Searches
- CDF Detector, Taus at CDF
- Event Selection
- Results
- Summary and Outlook

# Motivation: MSSM Higgs Search

- MSSM Higgs production enhanced at large  $\tan\beta$
- Substantial  $\text{BR}(A \rightarrow \tau\tau)$



- $\text{BR}(A \rightarrow b\bar{b})$  is larger, *however*, it is difficult to control backgrounds for  $gg, b\bar{b} \rightarrow A$

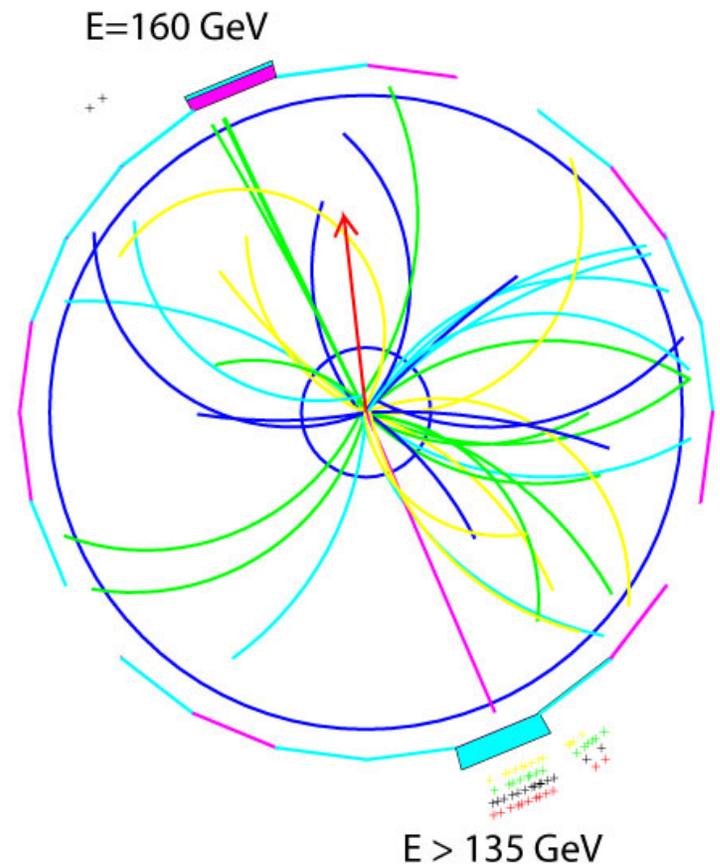
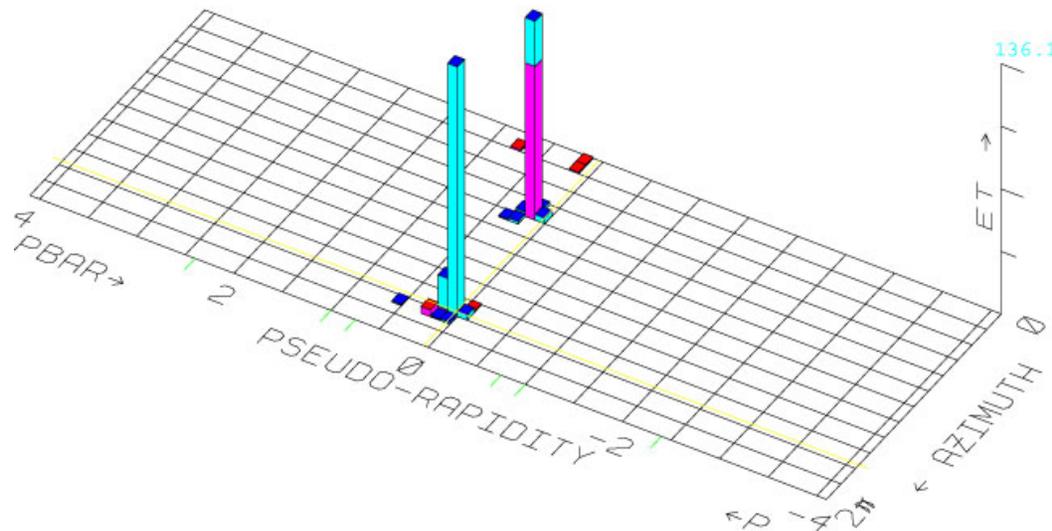
➔  $A \rightarrow \tau\tau$  is important for MSSM Higgs searches

# Motivation: Other “High-mass” $\tau\tau$

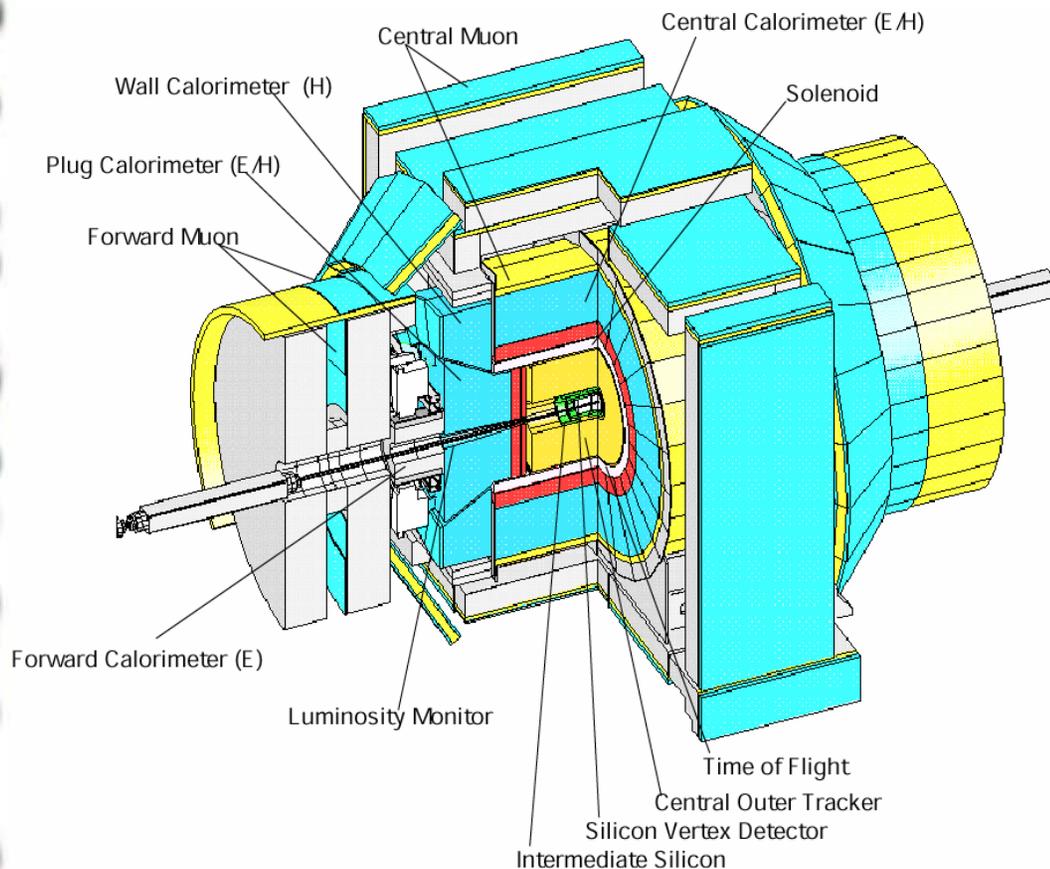
- Search for  $Z'$  with SM couplings, or
- Other exotic particles decaying to tau pairs

## “History”

Run 1 event with two very energetic tau candidates, and  $\cancel{E}_T$ .



# The CDF Detector at the Tevatron



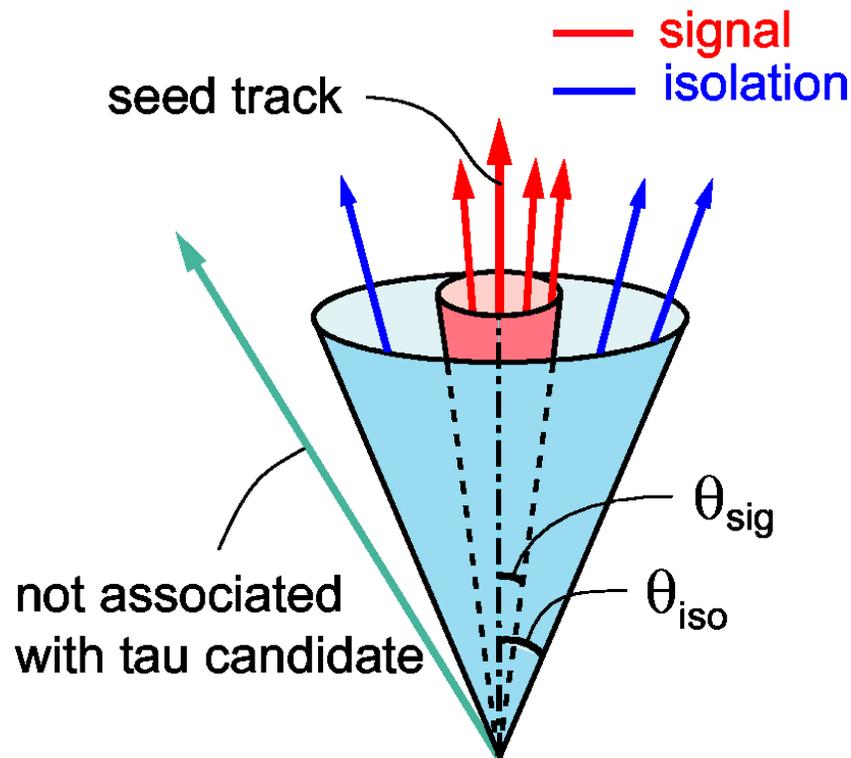
- Multipurpose detector for studying products of  $p\bar{p}$  collisions
- Tracking: SVX and Wire Chambers
- Calorimetry: EM, Hadronic, Shower Maximum for EM, Pre-shower Radiators
- Muon Detectors
- TOF System

# Taus at CDF in Run 2

- Build on the experience from Run 1
- Dedicated tau triggers:
  - Electron + isolated track
  - Muon + isolated track
  - Tau + Missing Transverse Energy
  - Di-tau
- Common Tau Reconstruction Framework
- **A Dedicated Tau Working Group serves as a driving force for analyses using tau leptons**

# Taus at CDF: Reconstruction

Refers to reconstruction of the visible products of semi-hadronic tau decays

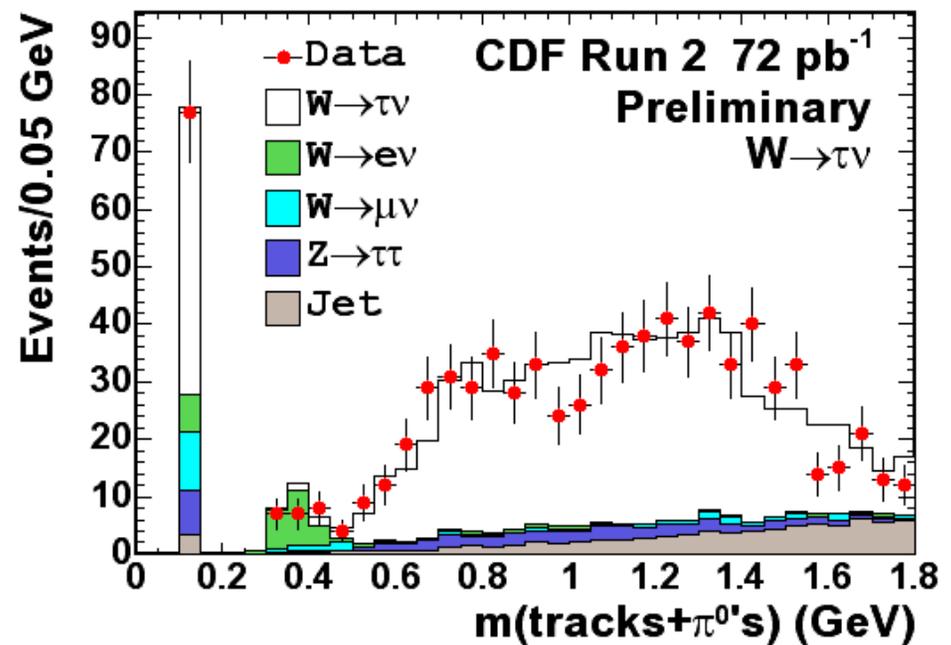
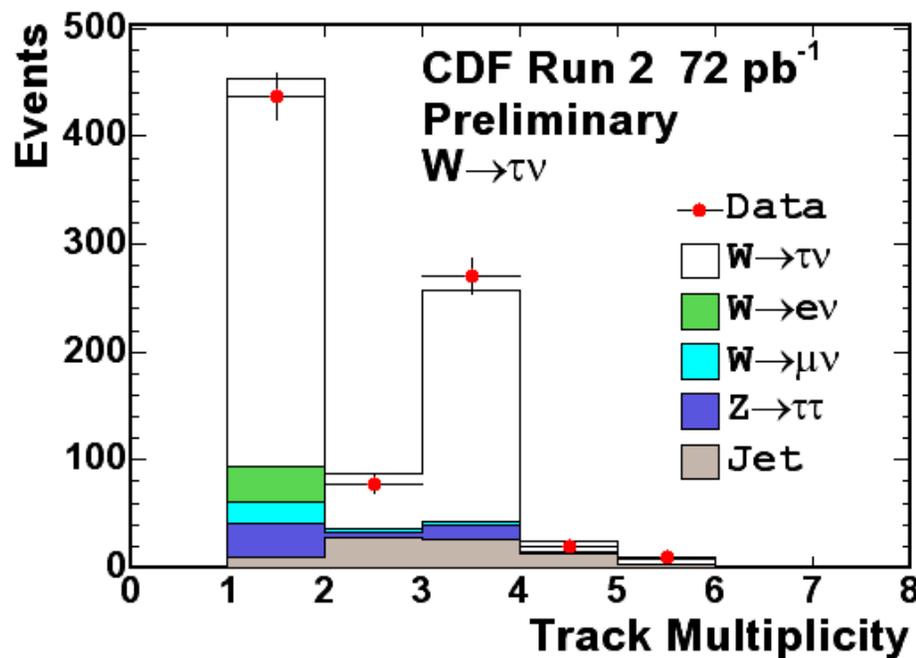


Tau signature in the detector:

- Narrow isolated jets
- Characteristic 1,3 track enhancement
- Low  $\pi^0$  multiplicity
- $M < 1.8$  GeV

# Taus at CDF: $W \rightarrow \tau \nu$

- W's are the largest source of isolated taus at CDF
- Select clean  $\tau$  sample:  $\cancel{E}_T > 30$  GeV, veto extra jets with  $E_T > 5$  GeV
- Natural choice for understanding tau reconstruction



- Good agreement between data and MC simulation

# Event Signatures of $\tau\tau$ Pairs

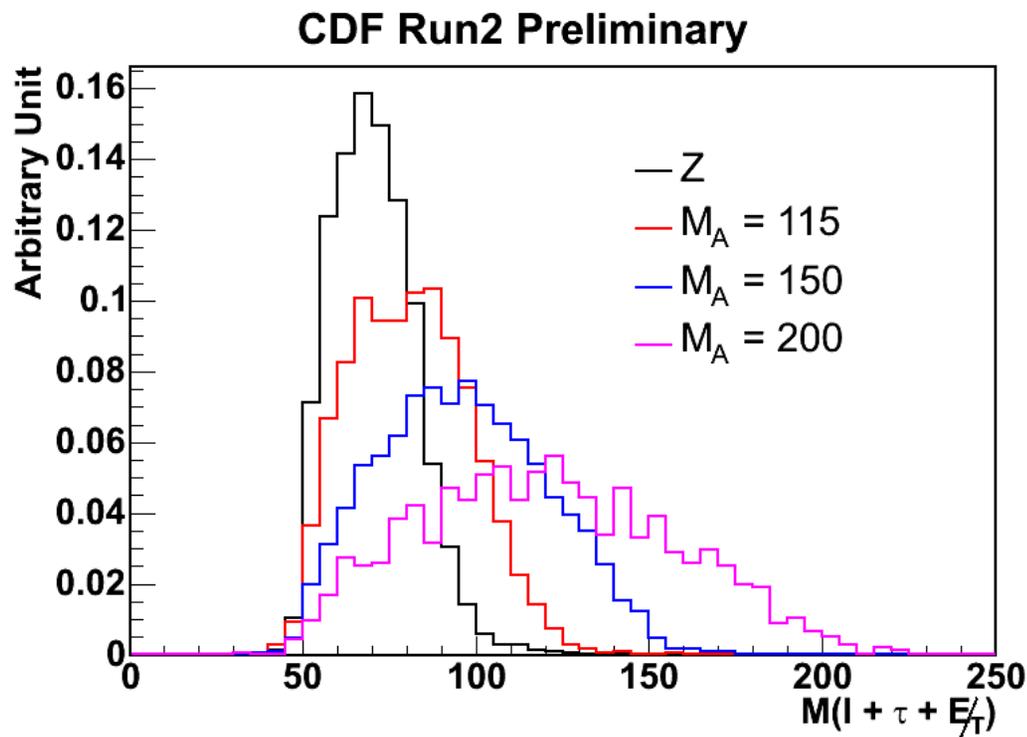
- Determined by the decay modes of the taus

Mode	Fraction (%)	Comment
$\tau_e\tau_e$	3	large $Z/\gamma^* \rightarrow ee$ bg
$\tau_\mu\tau_\mu$	3	large $Z/\gamma^* \rightarrow \mu\mu$ bg
$\tau_e\tau_\mu$	6	low jet backgrounds
$\tau_e\tau_h$	23	golden
$\tau_\mu\tau_h$	23	golden
$\tau_h\tau_h$	41	challenging (jet bg)

Throughout this talk we use  $\tau_e$ ,  $\tau_\mu$ ,  $\tau_h$  as shorthand notations for  $\tau \rightarrow e\bar{\nu}_e\nu_e$ ,  $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\mu$ , and  $\tau \rightarrow hadrons \nu_\tau$ , respectively.

# Can Z/Higgs and Z/Z' be Separated?

- Not enough information for full mass reconstruction
- Methods using  $\cancel{E}_T$  projection onto directions of visible decay products significantly reduce statistics
- Compromise: construct mass-like quantity  $M(\ell, \tau, \cancel{E}_T)$



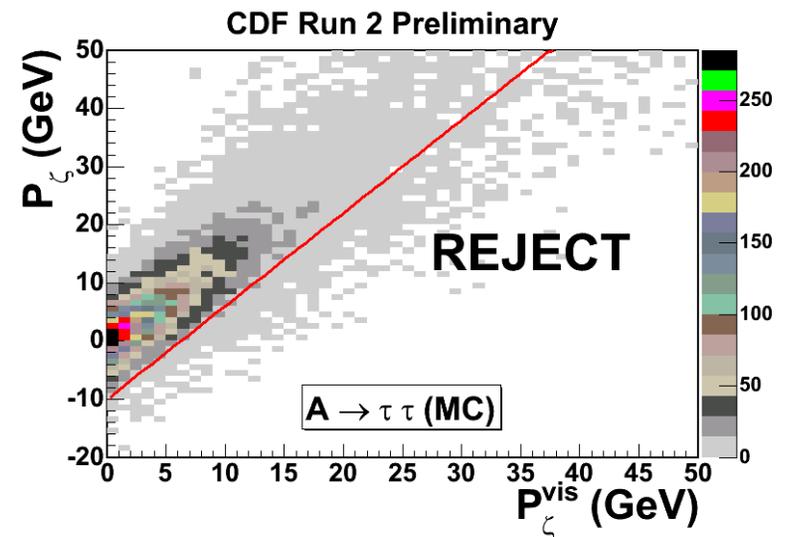
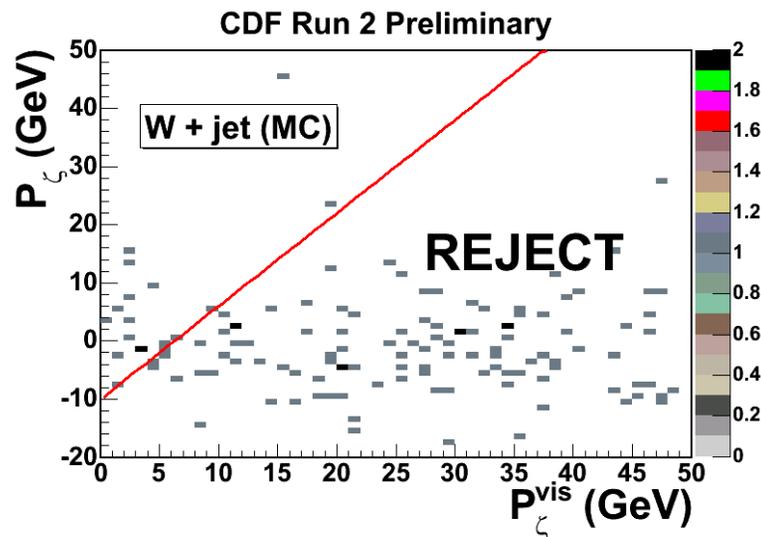
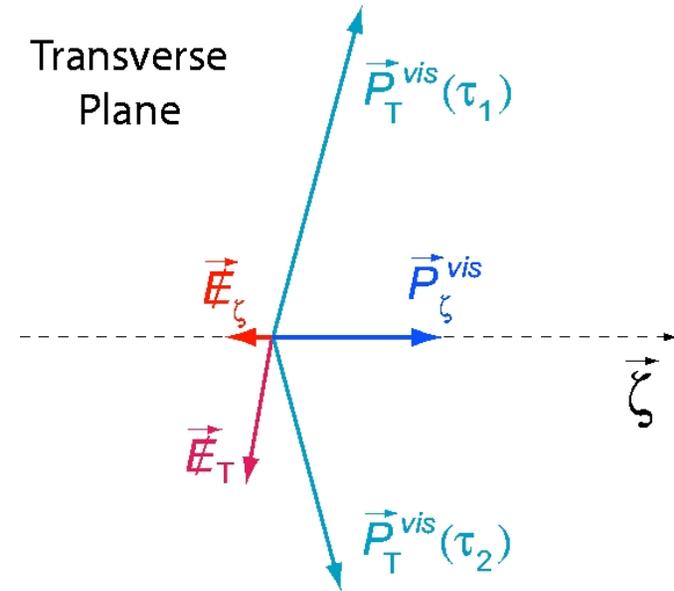
- ✗ Weaker discriminator than full mass
- ✗ Non-linear relation with mass
- ✓ Still, there is substantial non-overlapping region
- ✓ Can be calculated for all events

# Analyses:

- MSSM Higgs search in the region  $M_A=115-200$  GeV
  - Binned likelihood fit of  $M(\ell, \tau, \cancel{E}_T)$  to set limit
  - MC generated with  $\tan\beta=30$  used in acceptance estimation
- High-mass  $\tau\tau$  search  $M_{\tau\tau}=200-600$  GeV
  - Z mass region exclusion
  - Counting experiment
  - Uses  $Z'$  for acceptance

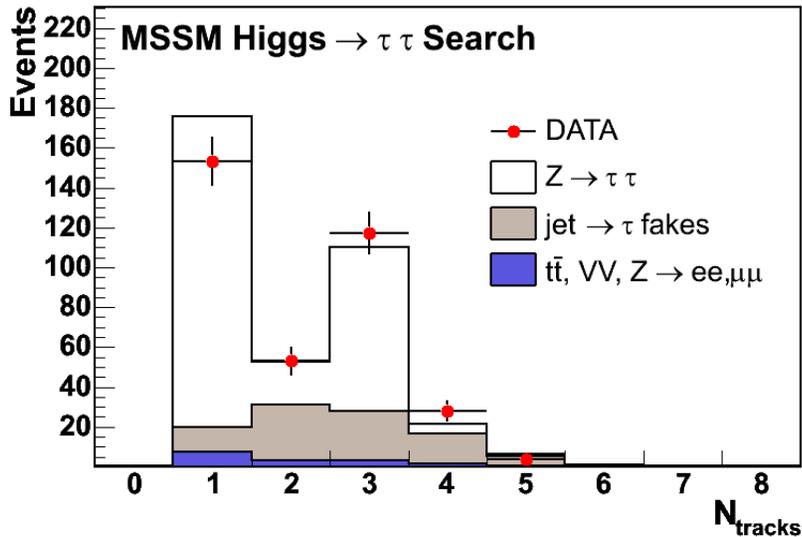
# MSSM Higgs Search: Event Selection

- Identify unique e,  $\mu$ ,  $\tau$  in the event
- Exactly one  $\tau_e\tau_h$  or  $\tau_\mu\tau_h$  candidate
- Suppress multi-jet bg:
 
$$|p_T^\ell| + |p_T^\tau| + |\cancel{E}_T| > 50 \text{ GeV}$$
- Relation between of  $\cancel{E}_T$ , e( $\mu$ ), and  $\tau$  used to suppress  $W \rightarrow \ell \nu + \text{jet}(s)$  (contributes to jet  $\rightarrow \tau$  fakes)



# Higgs Search: Observed Events

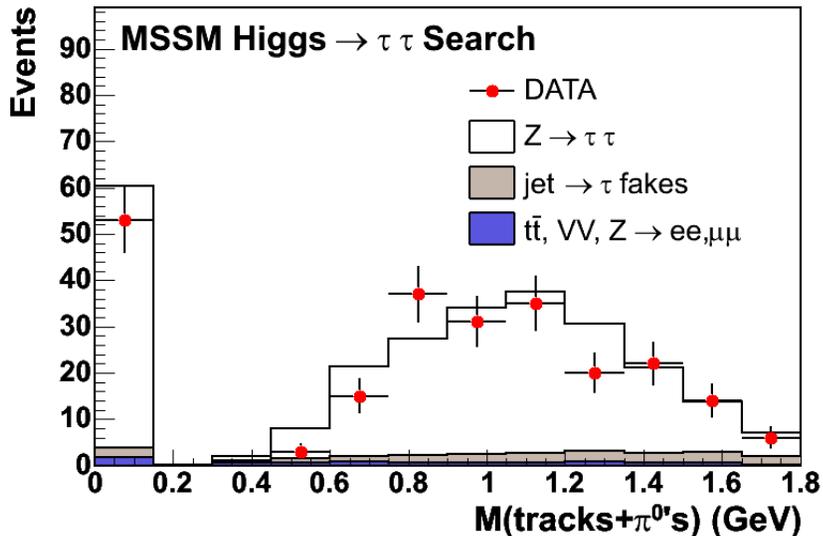
CDF Run 2 Preliminary (195 pb<sup>-1</sup>)



$\tau_e\tau_h$  and  $\tau_\mu\tau_h$  channels combined:

Track multiplicity of tau candidates before applying  $N_{\text{trk}}=1,3$  and  $Q^\ell Q^\tau = -1$

CDF Run 2 Preliminary (195 pb<sup>-1</sup>)



Mass distribution for tau candidates after applying  $N_{\text{trk}}=1,3$  and  $Q^\ell Q^\tau = -1$

(all subsequent plots and tables for the Higgs Search have these requirements applied)

# Higgs Search: Observed Events

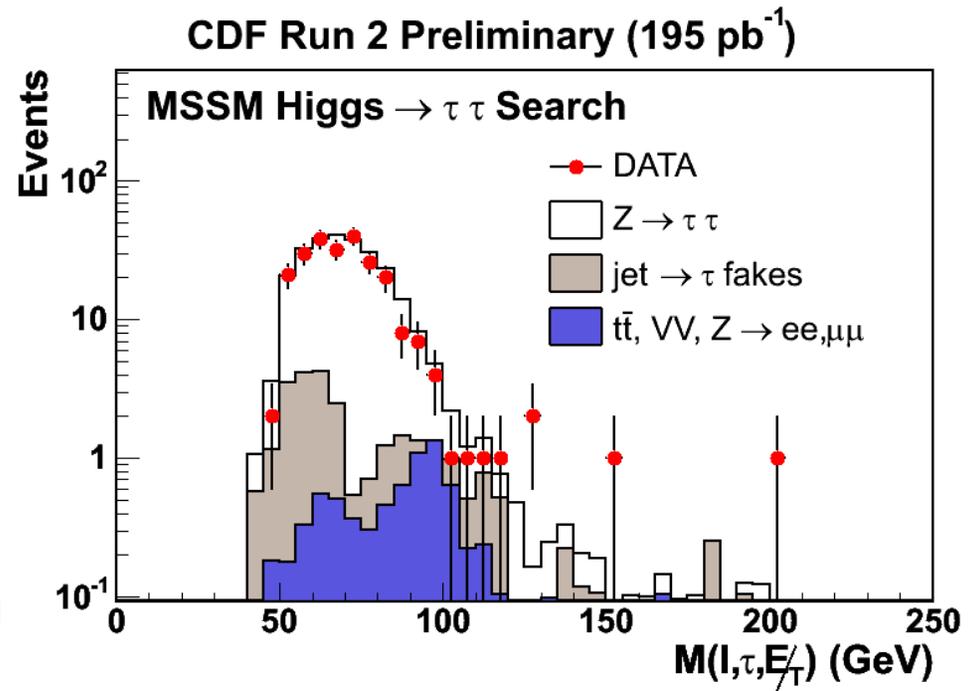
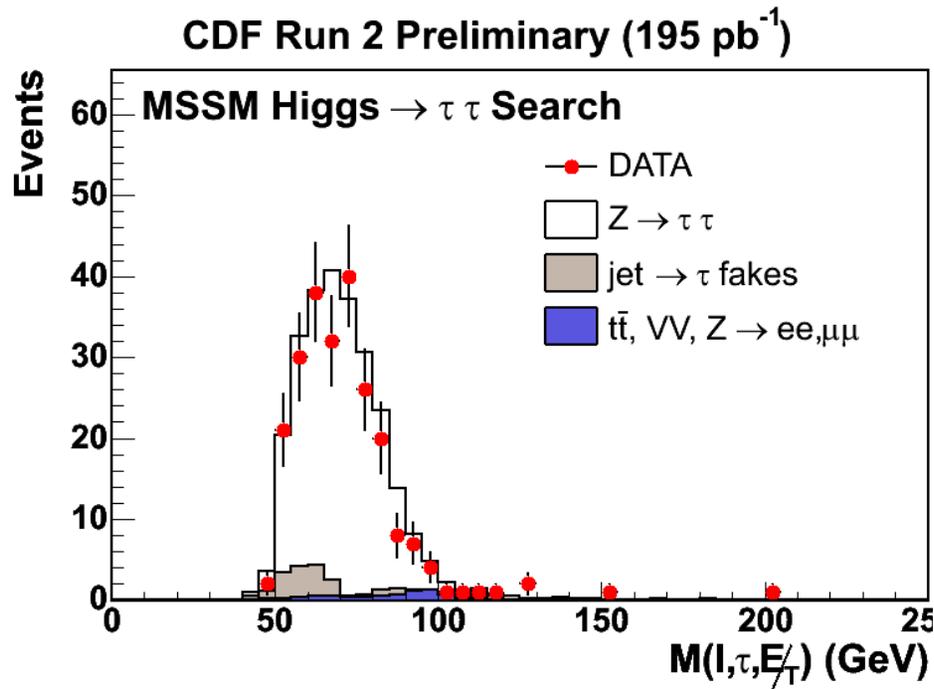
Predicted backgrounds and observed events

CDF Run 2 Preliminary (195 pb<sup>-1</sup>)

source	$\tau_e\tau_h$	$\tau_\mu\tau_h$	combined
$Z/\gamma^* \rightarrow \tau\tau$	$132.3 \pm 17.1$	$104.1 \pm 13.3$	$236.4 \pm 29.5$
$Z/\gamma^* \rightarrow ee, \mu\mu$	$1.8 \pm 0.2$	$4.9 \pm 0.4$	$6.7 \pm 0.6$
$VV, t\bar{t}$	$0.7 \pm 0.1$	$0.8 \pm 0.1$	$1.5 \pm 0.1$
jet $\rightarrow\tau$ fakes	$12.0 \pm 3.6$	$7.0 \pm 2.1$	$19.0 \pm 5.7$
<b>Total predicted BG</b>	<b><math>146.8 \pm 17.5</math></b>	<b><math>116.8 \pm 13.5</math></b>	<b><math>263.6 \pm 30.1</math></b>
<b>Observed</b>	<b>133</b>	<b>103</b>	<b>236</b>

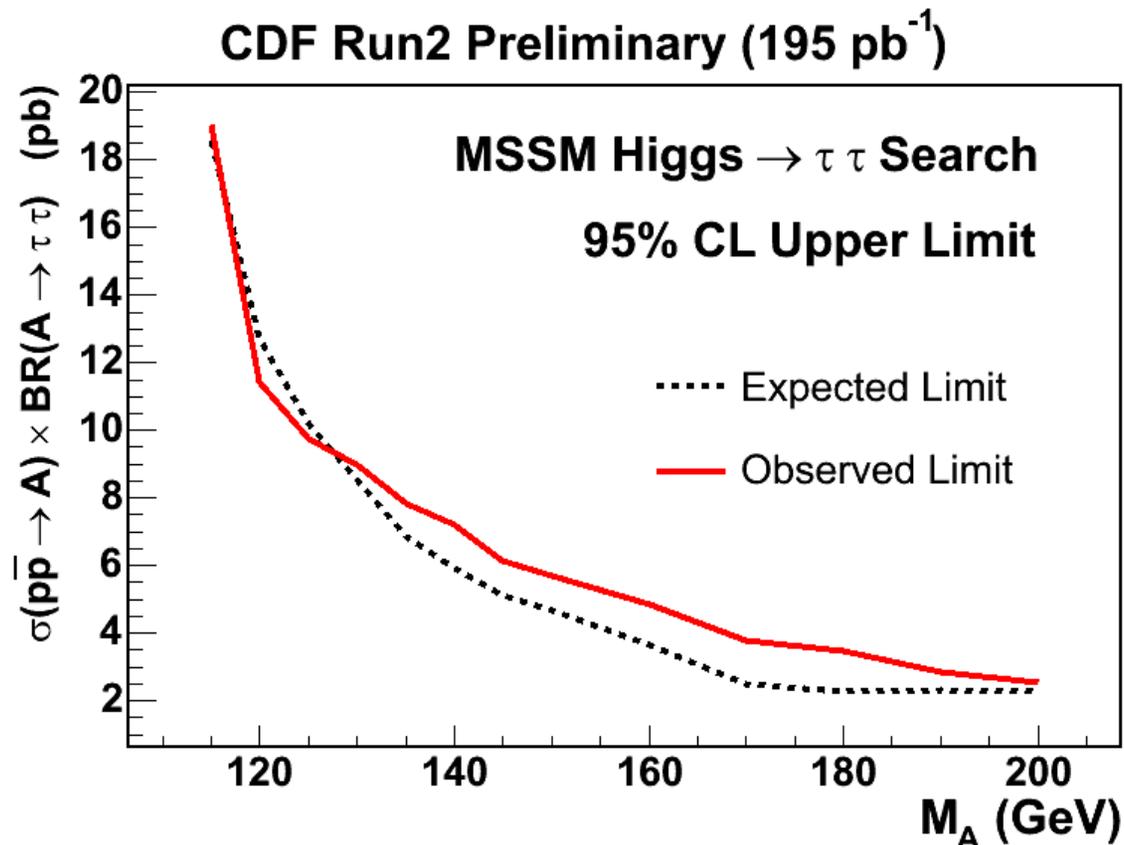
- ✓ Prediction and observation in agreement within errors (assuming no Higgs signal)

# Higgs Search: $M(\ell, \tau, \cancel{E}_T)$



- The 95% CL upper limits are extracted using a binned likelihood fit of the  $M(\ell, \tau, \cancel{E}_T)$  distributions
- The observed limits are compared with pseudo-experiment predictions

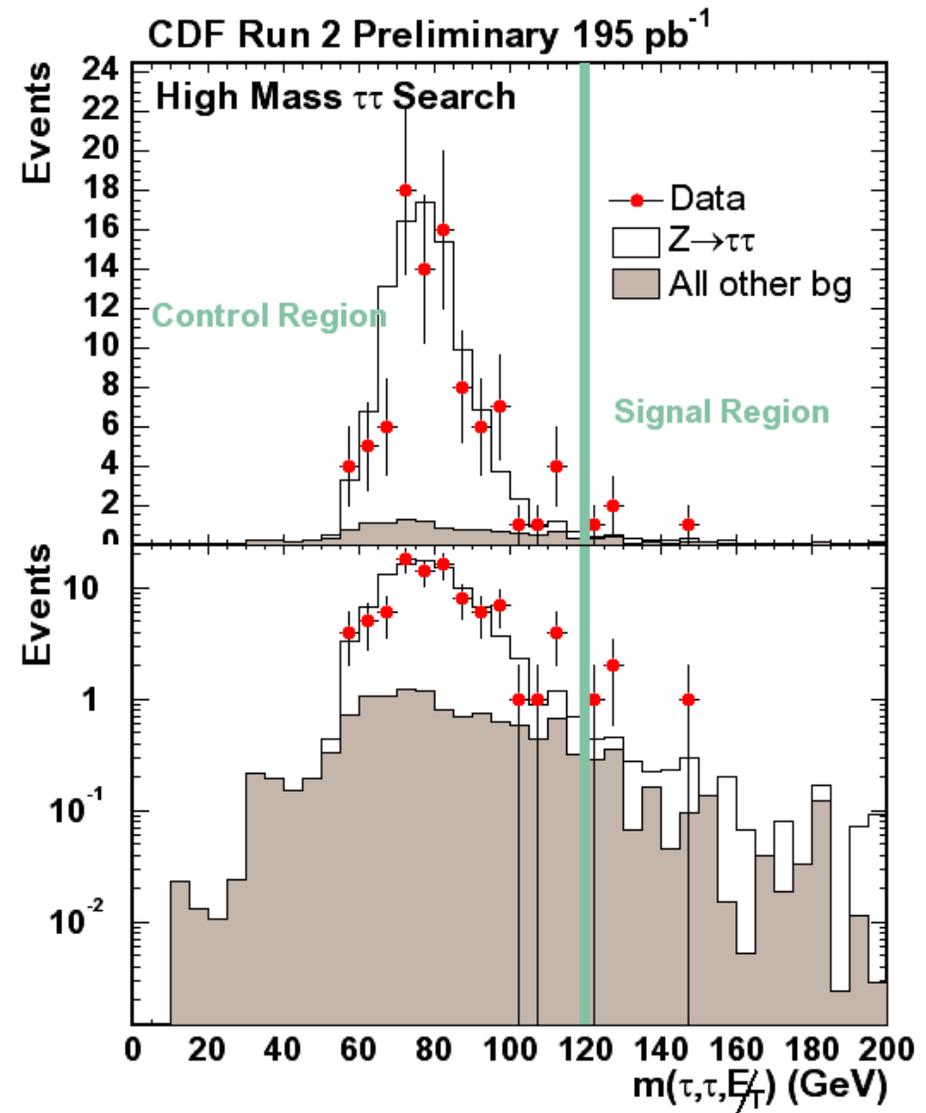
# Higgs Search: 95% CL Upper Limit



- MC generated with  $\tan\beta=30$  used in acceptance estimation
- Observed limits fall in the realm of theory predictions for large  $\tan\beta$ , where Higgs width becomes a factor for acceptance

# $Z' \rightarrow \tau\tau$ Search: Event Selection

- Require  $\tau_e\tau_h$ ,  $\tau_\mu\tau_h$ , or  $\tau_h\tau_h$
- $\cancel{E}_T > 15$  GeV
- $|\Delta\phi(\tau_\ell, \cancel{E}_T)| < 30^\circ$  ♦
- Suppress  $Z \rightarrow \tau\tau$ :  
 $M(\tau, \tau, \cancel{E}_T) > 120$  GeV
- Blind analysis
  - control region:  
 $M(\tau, \tau, \cancel{E}_T) < 120$  GeV
  - Signal region:  
 $M(\tau, \tau, \cancel{E}_T) > 120$  GeV
- “Counting experiment”



- ♦ Here  $\tau_\ell$  is either  $\tau_e$ ,  $\tau_\mu$ , or the lower- $p_T$   $\tau_h$  (in  $\tau_h\tau_h$  case)

# $Z' \rightarrow \tau\tau$ Search: Observed Events

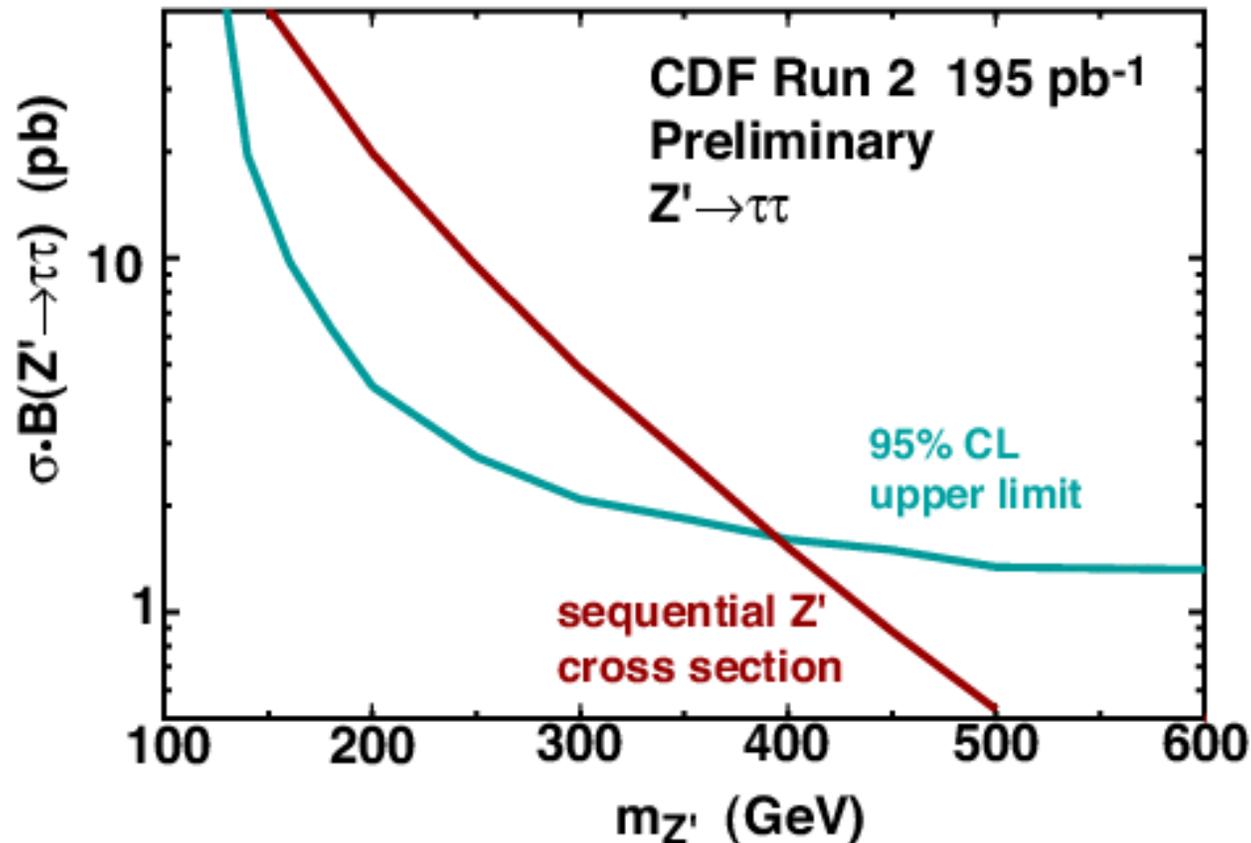
Predicted backgrounds and observed events

CDF Run 2 Preliminary (195 pb<sup>-1</sup>)

source	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$	combined
$Z/\gamma^* \rightarrow \tau\tau$	$0.56 \pm 0.11$	$0.50 \pm 0.09$	$0.36 \pm 0.08$	$1.42 \pm 0.19$
$Z/\gamma^* \rightarrow ee$	$0.16 \pm 0.14$	0	0	$0.16 \pm 0.14$
$Z/\gamma^* \rightarrow \mu\mu$	0	$0.50 \pm 0.25$	0	$0.50 \pm 0.25$
jet $\rightarrow$ $\tau$ fakes	$0.29 \pm 0.14$	$0.18 \pm 0.09$	$0.28 \pm 0.10$	$0.75 \pm 0.19$
<b>Total predicted BG</b>	<b><math>1.01 \pm 0.23</math></b>	<b><math>1.18 \pm 0.28</math></b>	<b><math>0.64 \pm 0.13</math></b>	<b><math>2.83 \pm 0.39</math></b>
<b>Observed</b>	<b>4</b>	<b>0</b>	<b>0</b>	<b>4</b>

- No significant excess of events observed
- The 95% CL upper limits are extracted as a function of  $Z'$  mass

# $Z' \rightarrow \tau\tau$ Search: 95% CL Upper Limit



- $Z'$  with SM couplings used in estimating acceptance
- Sequential  $Z'$  boson with mass below 394 GeV is excluded at 95% CL

# Summary and Outlook

- We have performed searches for neutral bosons decaying to  $\tau\tau$
- No excess events were observed in the high-mass  $\tau\tau$  search;  $Z'$  with  $M_{Z'} < 394$  GeV is excluded at 95% CL (for SM couplings)
- MSSM Higgs search shows no evidence of signal at current sensitivity. We set upper limits at 95% CL for  $M_A = 115-200$  GeV
- More data and additional  $\tau\tau$  decay channels will be included
- Exclusive search for  $Ab(b)$  ( $A \rightarrow \tau\tau$ ) final state
- Improvements in systematics, tau reconstruction, and  $Z$ /Higgs separation are on the way
- Examine the impact of the high-mass  $\tau\tau$  results on production of particles other than sequential  $Z'$

Stay tuned for more exciting results in the *very* near future!